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STRUCTURING CAUSED BY RAYLEIGH-TAYLOR INSTABILITY.(U)

APR 82 S BRECHT, E HYMAN, P J PALMADESSO

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The structuring that a LWIR system might detect is addressed in this report. This research was performed by incorporating the results of an analytic study of Rayleigh-Taylor instabilities into a code which tracks the temporal behavior of various plasma quantities. The results indicate that structuring will occur in times less than 5 secs. Estimates of maximum and minimum wavelengths and of growth rates are provided. The structured regions contain sizable concentrations of metallic and oxygen ions and may well present difficulties to LWIR systems depending on the chemical activity present in the structure.

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STRUCTURING CAUSED BY RAYLEIGH-TAYLOR INSTABILITY

In addressing the question of the wavelengths of structures that LWIR sensors might encounter in an atmosphere disturbed by a high altitude nuclear event we have made use of some calculations and models developed for DNA to address the early time jetting of plasma across magnetic field lines and field aligned acceleration of plasma. These calculations and models make use of the detailed work on the collisionless coupling between expanding debris and ambient air. It is our opinion that structure created at early times, i.e., < 10 sec will greatly affect systems for hundreds of seconds after the burst. In addition to effects on the system produced by stimulated plasma emission from high electron densities, we feel that radiation from or scatter by metallic ions or their oxides resulting from chemistry during the mixing of high densities of metallic ions and oxygen could present a major problem to LWIR systems. This latter effect could be particularly important in regions either horizontal to or above the burst point where electron densities are not expected to be extremely large.

The calculation of the minimum and maximum wavelengths for the structure is based on studies of the Rayleigh-Taylor instability. The Rayleigh-Taylor instability has been discussed for many years as a candidate for causing early time structure particularly in situations where the plasma is collisional, such as low altitude bursts or perhaps the bottom side of a standard Spartan. One of the earliest references is probably Zinn et al., 1965. The Rayleigh-Taylor instability that will be discussed here is driven by terms that result from small scale kinetic instabilities which provide the interaction between rapidly expanding debris and air in a collisionless plasma (Lampe et al., 1975, and Clark and Papadopoulos, 1976). It is found that this interchange instability is operative during a high altitude nuclear detonation (Brecht and

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Papadopoulos, 1979). Comparison between Starfish data and the predictions of phenomena resulting from this instability appear to agree and explain the existence of very high altitude debris in times less than 30 sec (Brecht et al., 1981).

A very brief summary of the expected dynamics of the plasma is as follows. As the ionized debris expands outward from the burst point it interacts with the ambient air. At lower altitudes ($\lesssim$ 150 km) this interaction is collisional. For high altitude bursts and especially for the portion of the burst going upward, classical collisions are rare. In this latter case plasma instabilities are excited which couple the expanding debris and the air to form a shock. The very thin region which interfaces the bulk of the expanding debris and the cold air is called the coupling shell. Within this region resides the metallic debris and the air ions that are picked up and mixed. The dynamics here is extremely complicated but suffice it to say that it provides the mechanism for the Rayleigh-Taylor instability described by Brecht and Papadopoulos. This instability occurs with very definite upper and lower limits on participating wavelengths. These limits depend on local plasma parameters such as temperature, density, magnetic field, and gradient scale lengths. Once the instability is operative it can reach the nonlinear regime where the pertubations to the expanding shell can actually detach themselves from the shell and E x B drift across the magnetic field lines. This kind of jetting was observed in Starfish and has certain characteristics that allow comparison between data and this theory (Brecht et al., 1981). The result of all this is that not only is the expanding shell expected to be structured, but one could also reasonably expect discrete blobs of plasma to break off.

The data displayed here is the result of merging the Rayleigh-Taylor calculations with a code which models the temporal evolution of the basic plasma parameters in the coupling shell. This code is called SCORPIO and is basically described in a report by Clark and Papadopoulos (1976). It is not a hydrocode, but a code developed to model the evolution of the coupling shell in terms of thickness, temperature, plasma density, and field aligned acceleration. It maintains an energy budget and depletes the coupling shell of material and energy in a time dependent fashion consistent with our best knowledge of the microphysics active in this region. For general hydro it relies on a snowplow model. Therefore the global features such as radius are not as accurate as the high resolution codes from which it is derived.

The result of uniting the Rayleigh-Taylor theory with the SCORPIO code are shown in the accompanying figures. Figure 1 shows the maximum and minimum wavelength for the instability as a function of time for several angles relative to the ambient field direction. The data here is displayed as a function of angle where zero is along the field line in a downward direction. One finds that the instability for a standard Spartan begins to grow one second after the detonation. Note that the squares represent the maximum wavelengths and the triangles the minimum. The wavelengths range from about 1 km to 20 km for the various angles. The size of the actual striation will of course be 1/2 the wavelength. Therefore this instability induces structures ranging in size from ~ 0.5 km to ~ 10 km at times of 5 sec or less. Figure 2 shows the growth rates associated with the instability at the maximum and minimum wavelengths. The convention for the boxes and triangles carries over to these plots. The boxes represent the growth rate for the maximum wavelength and so forth. One notes here that

the maximum wavelengths have the highest growth rates. It is expected that the long wavelength modes would go unstable first and, having reached saturation, the shorter wavelength modes would develop.

Figure 3 shows ion density in the coupling shell as a function of time. It is expected that the ion density in the coupling shell will be representative of the density in the structures at the time of instability onset. The line denoted by the squares represents the total ion density in the shell including both debris and picked up air. The calculation continuously accounts for the loss of ions down the field lines due both to thermal effects and to field aligned acceleration. The second line (triangles) is our best estimate of debris density. It has been assumed that the nominal mass of the ion is 27. It is this second line that we feel provides cause for concern. At times of 2 seconds one finds debris density of 10^6 cm^{-3} or so. We have not done the chemistry here, but oxidation processes occurring on the time scales of interest (100 sec), would provide large amounts of radiation in the LWIR. Figure 4 shows the ion temperature as a function of time and angle. One notes that in the direction upward the temperature remains high. The ions will, in fact continue to cool at later times, but by this time pieces of the plasma may be well removed from the original disturbed region.

Figure 5 gives the radius of burst as a function of time and angle as computed by the code. It is here to provide general information regarding the calculation.

These then are the data resulting from merging the analytic treatment of the Rayleigh-Taylor instability with the large scale numerical results. The data has been limited to times of 5 secs and earlier and angles of 72^o or higher. The latter limitation is due to the increasing

classical collisionality in the downward direction for bursts of this altitude. For very high altitude bursts these restrictions on the output can be relaxed. As mentioned earlier the theory did not include classical collisions and therefore any numbers, no matter how reasonable, are suspect in regions where classical collisions are dominant.

The results of this work indicate several features that must be considered in assessing the LWIR problem. First, there will be structuring and transport of ionic material across magnetic field lines. Second, the material will consist of metallic debris in significant concentration, as well as oxygen that is picked up by the expanding debris. If the Starfish data is any indication some of this material will be found at large distances from the burst point. Finally, the size of the structured material will range from 0.5 km to ~ 10 km. The instability favors longer wavelengths, but the shorter ones can grow on the large scale perturbations. The initial structure is expected to form in less than 5 sec after detonation and remain for hundreds of seconds.

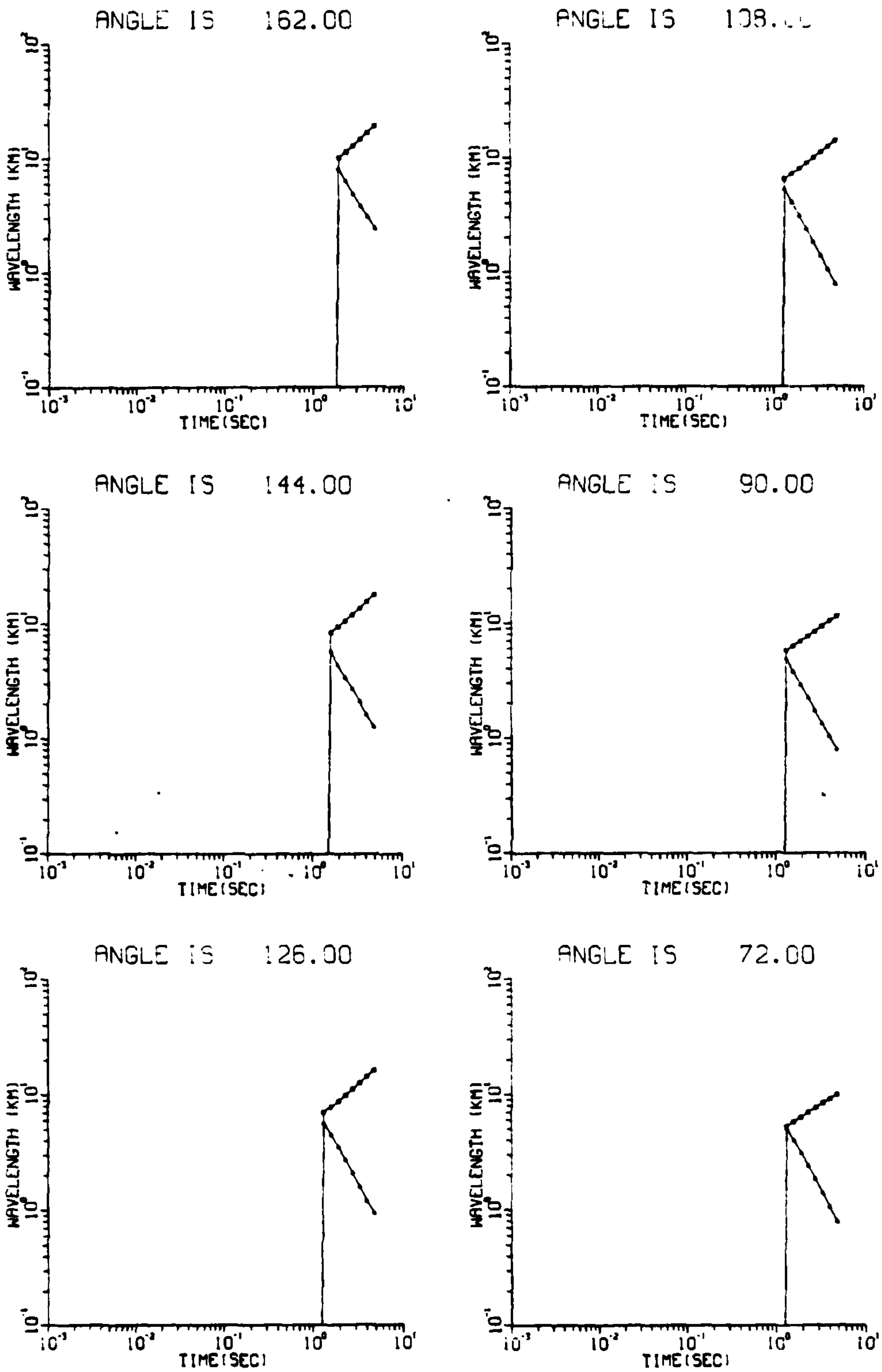

Fig. 1 - Maximum and minimum wavelength as a function of time. The angles shown on each plot with respect to the local magnetic field line with zero being directed downward.

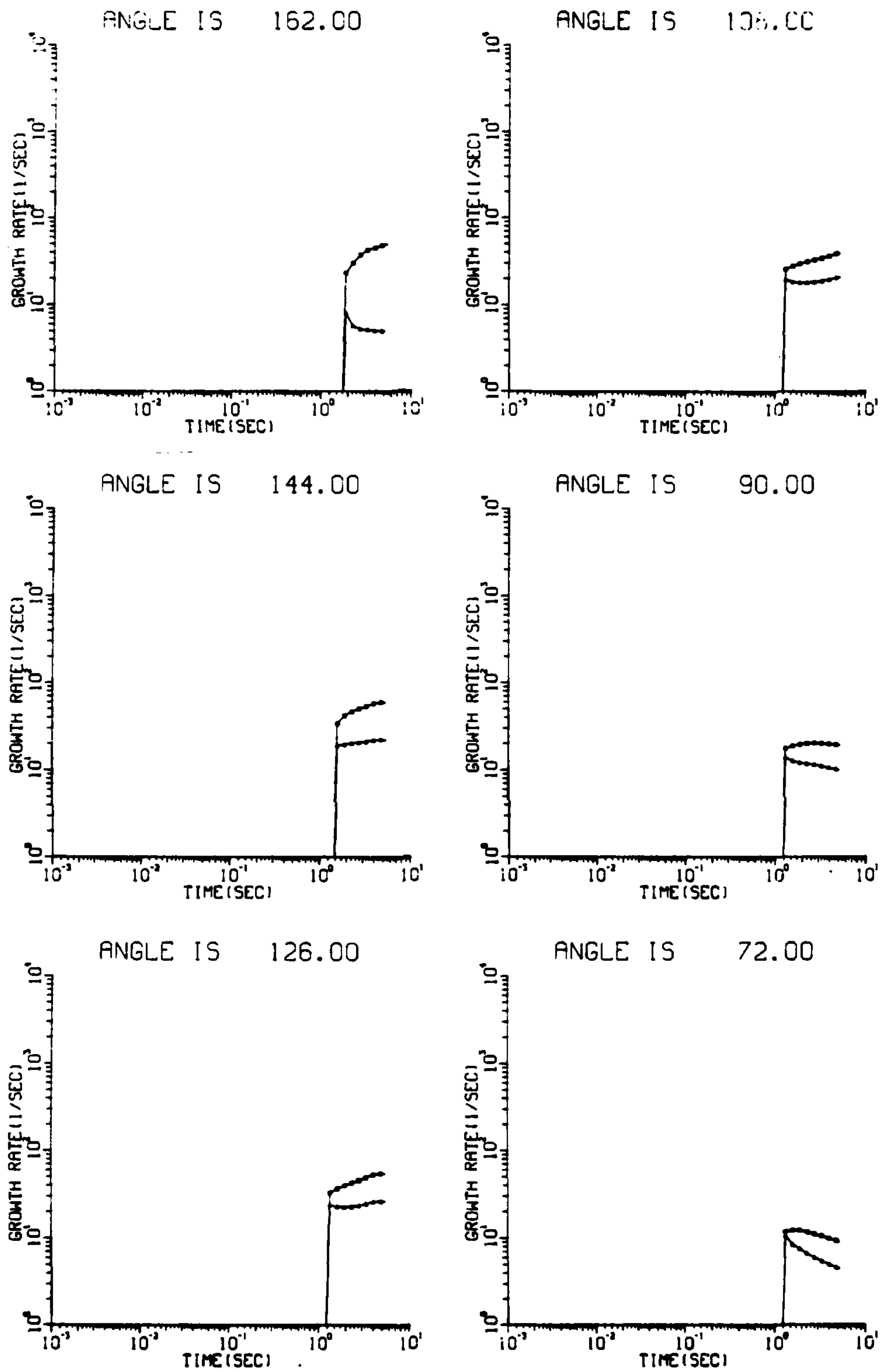

Fig. 2 - Growth rates for the maximum and minimum wavelength. The squares refer to the maximum wavelength and the triangles refer to the minimum wavelength.

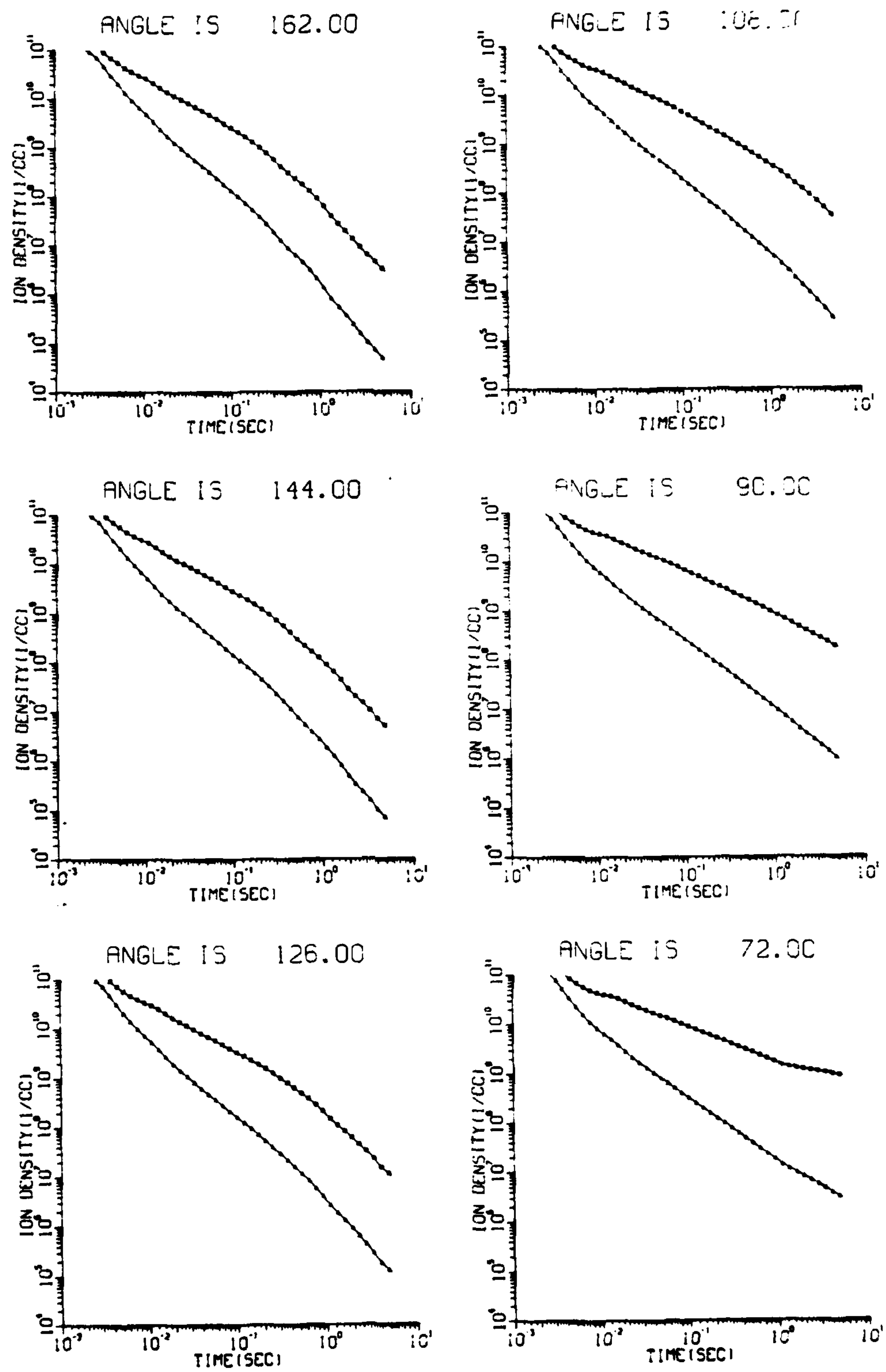

Fig. 3 - Ion density as a function of time for various angles. Squares represent total ion density. The triangles represent debris ion density, assumed mass 27.

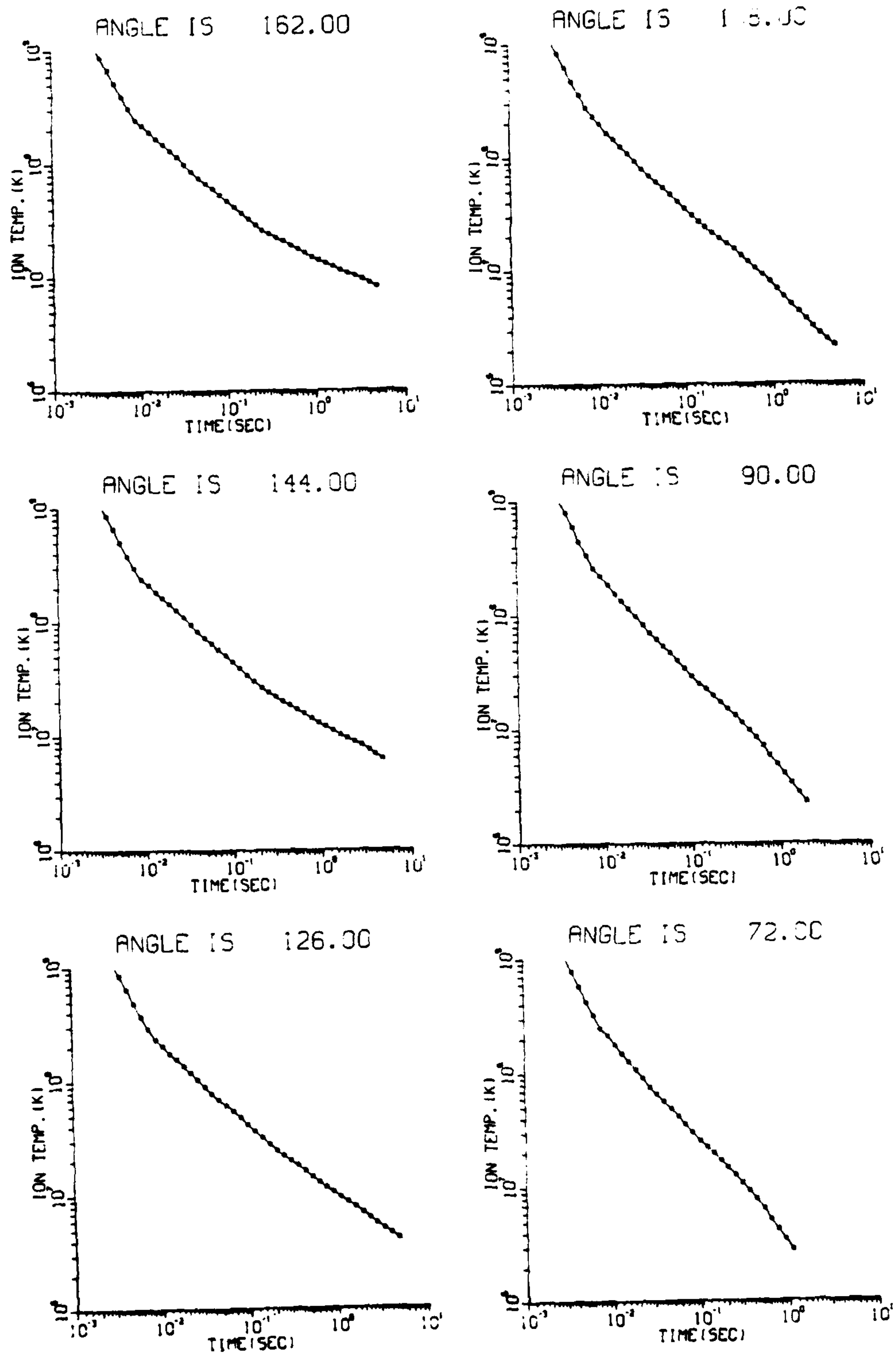

Fig. 4 - Ion temperature as a function of time for various angles with respect to the magnetic field lines.

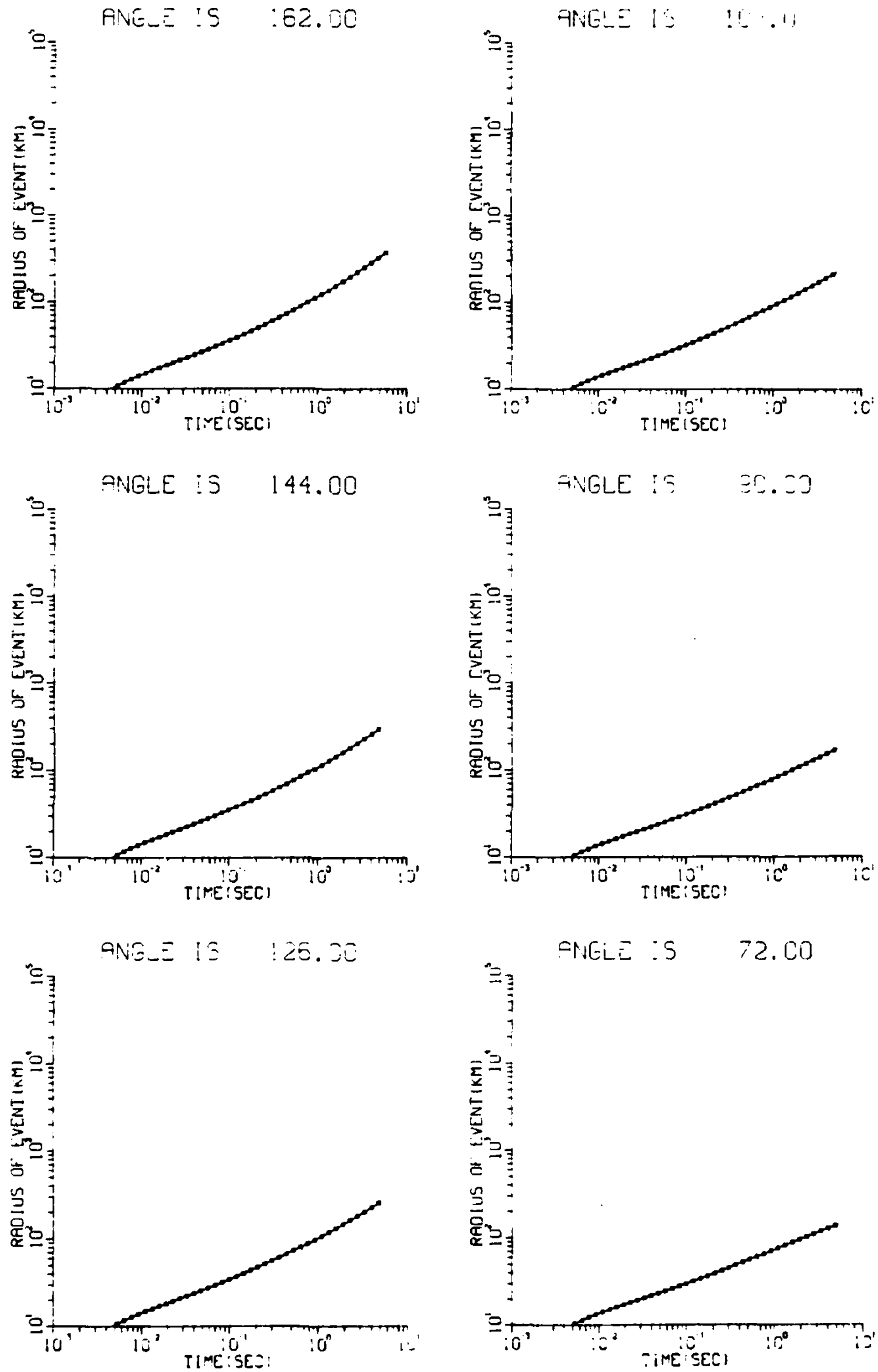

Fig. 5 - Radius of coupling shell for relevant angles and times

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